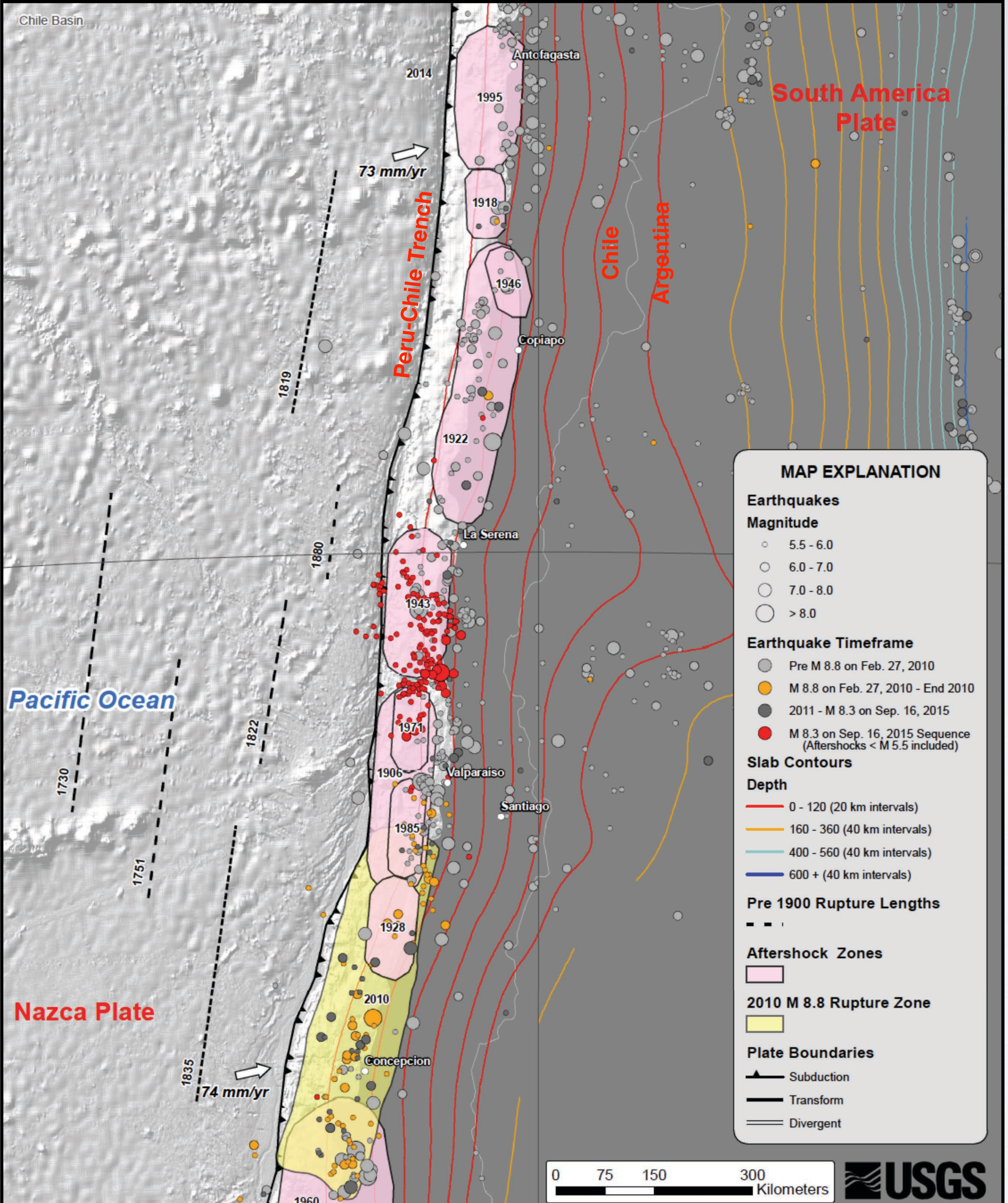
The Mw 8.3 September 16, 2015 Coquimbo, Chile Earthquake and Associated Aftershock Sequence

Earthquake Educational Slides

Created & Compiled by Will Yeck[1], Matt Herman[2], Jennifer Nealy[1], Gavin Hayes[1], Bill Barnhart[3], Greg Smoczyk[1], Paul Earle[1], David Wald[1], Rich Briggs[1], Harley Benz[1] and Kevin Furlong[2]

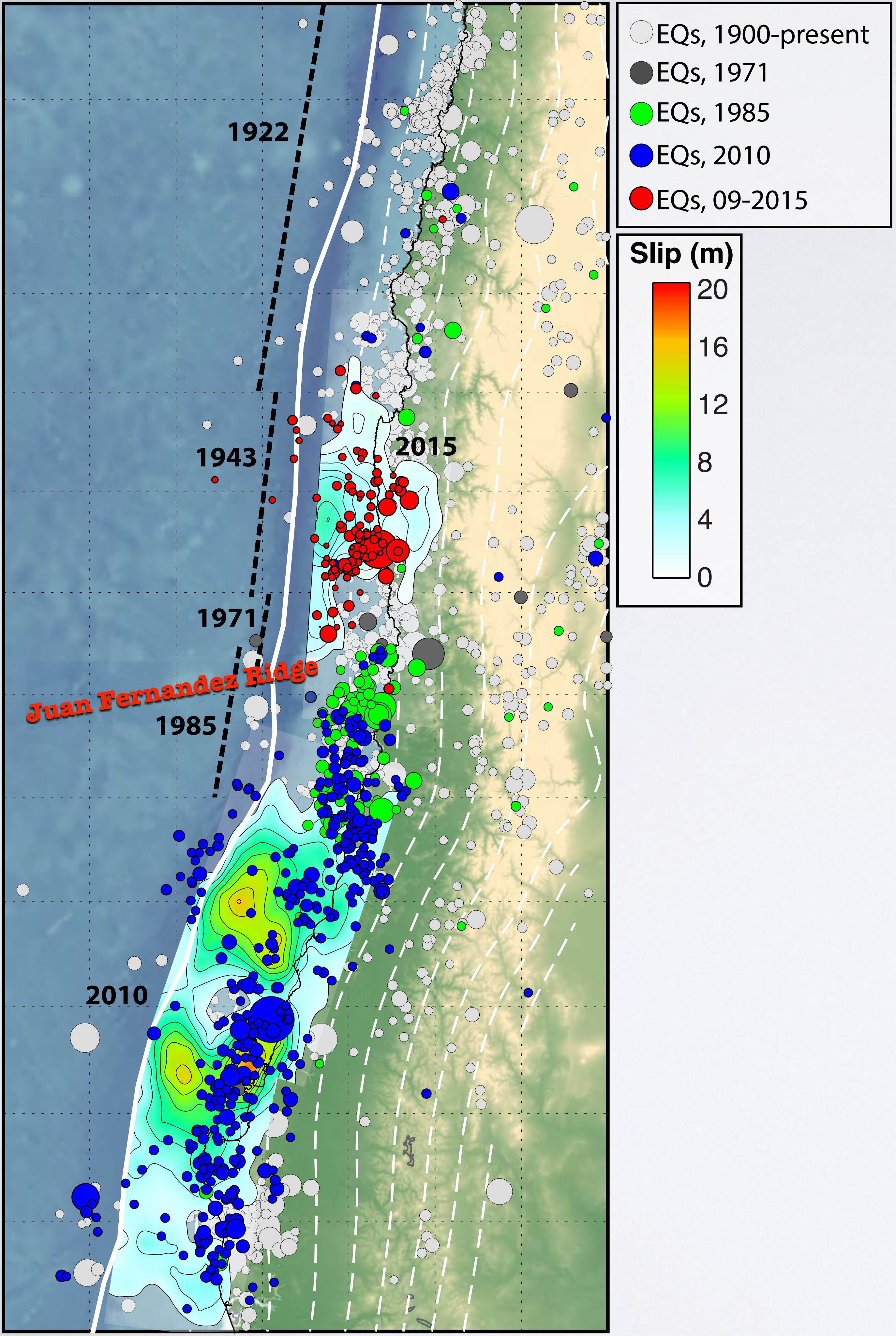
[1]USGS National Earthquake Information Center, Denver, CO
[2]Geodynamics Research Group, Penn State University, State College, PA
[3]Dept. of Earth and Environmental Sciences, Univ. of Iowa, Iowa City, IA

Results are preliminary and should not be considered as final USGS products. Slides are intended as educational tools, either combined or on a individual basis.



Seismotectonics

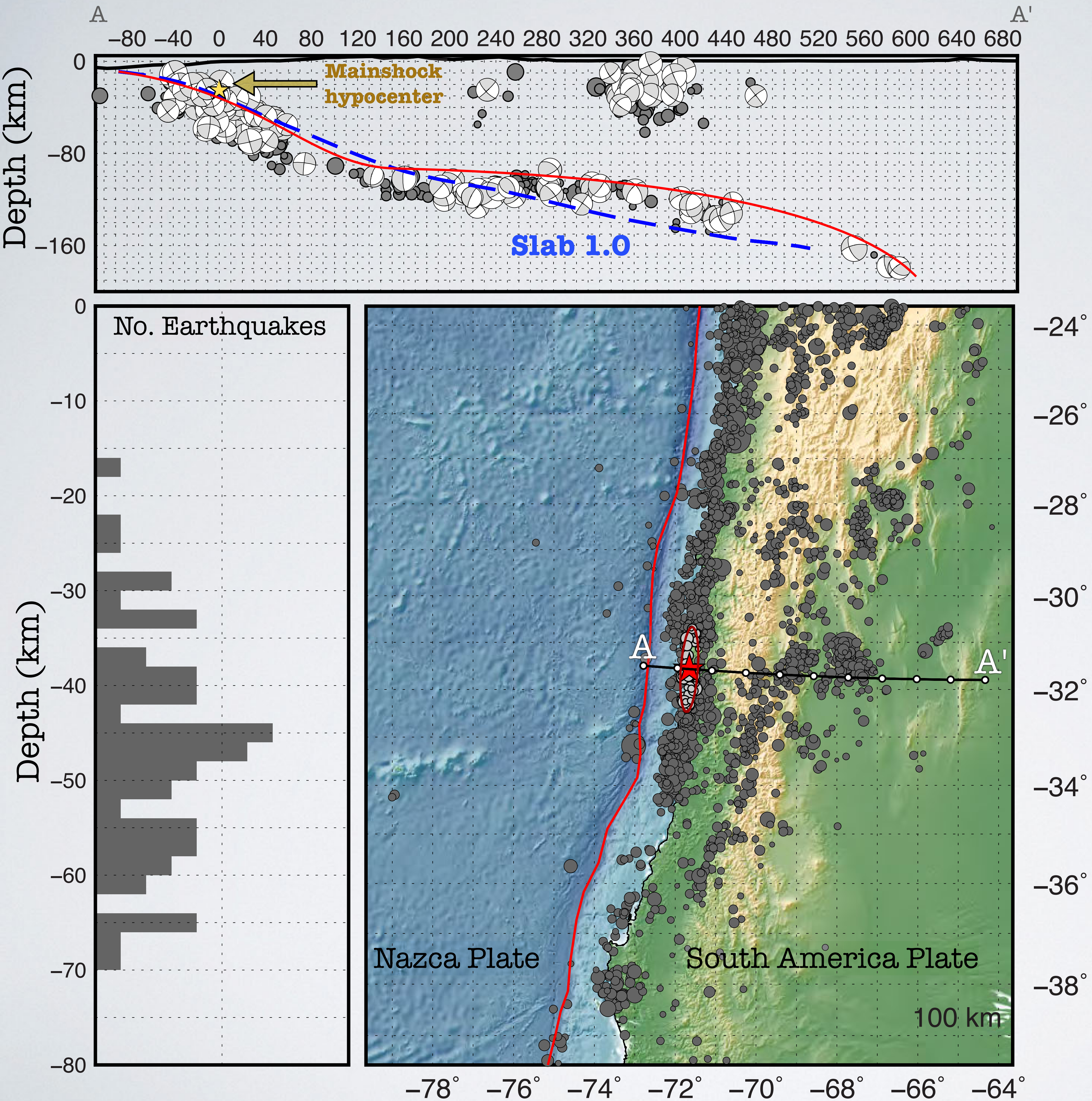
The September 16, 2015 M 8.3 earthquake occurred ~ 7 km offshore of Central Chile, as a result of thrust faulting on the interface between the Nazca and South America plates. At the latitude of this event, the Nazca plate is moving towards the east-northeast at a velocity of 74 mm/yr with respect to South America, and begins its subduction beneath the continent at the Peru-Chile Trench, 85 km to the west of the September 16 earthquake. The size, location, depth (~26 km) and mechanism of this event are all consistent with its occurrence on the megathrust interface in this region.



A Century of Large Earthquakes in Central Chile

Chile has a long history of massive earthquakes, including the 2010 M 8.8 Maule earthquake in Central Chile, which ruptured a ~400 km long section of the plate boundary south of this 2015 event (and to the south of the Juan Fernandez Ridge, which enters the trench immediately south of the 2015 earthquake). Over the century prior to the September 16, 2015 earthquake, the region within 400 km of this event has hosted 15 other M 7+ earthquakes including the M 8.0 and M 7.5 1985 Valparaiso earthquakes. This subduction zone also hosted the largest earthquake on record, the 1960 M 9.5 earthquake in southern Chile.

Nazca - South America Plate Interface

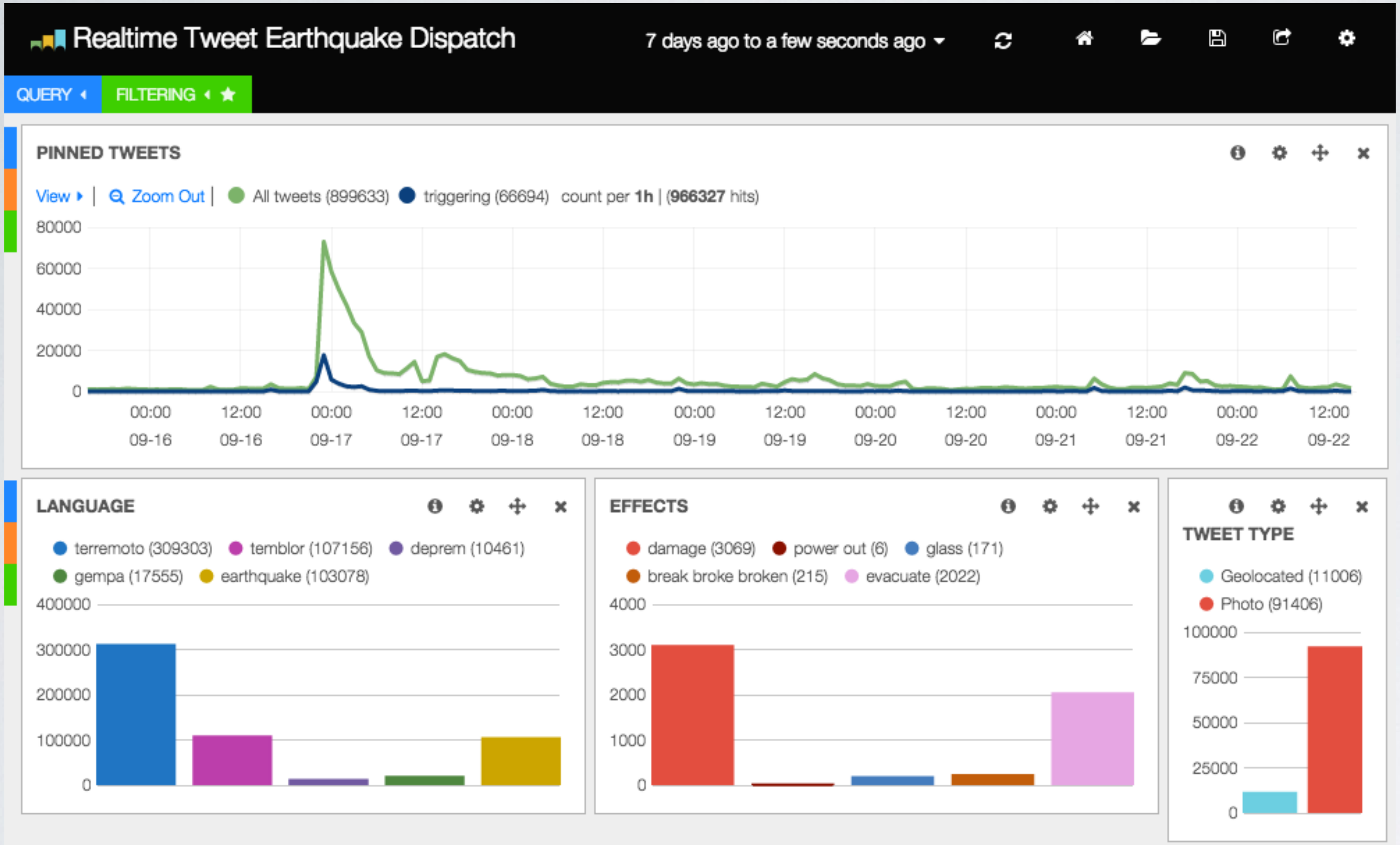


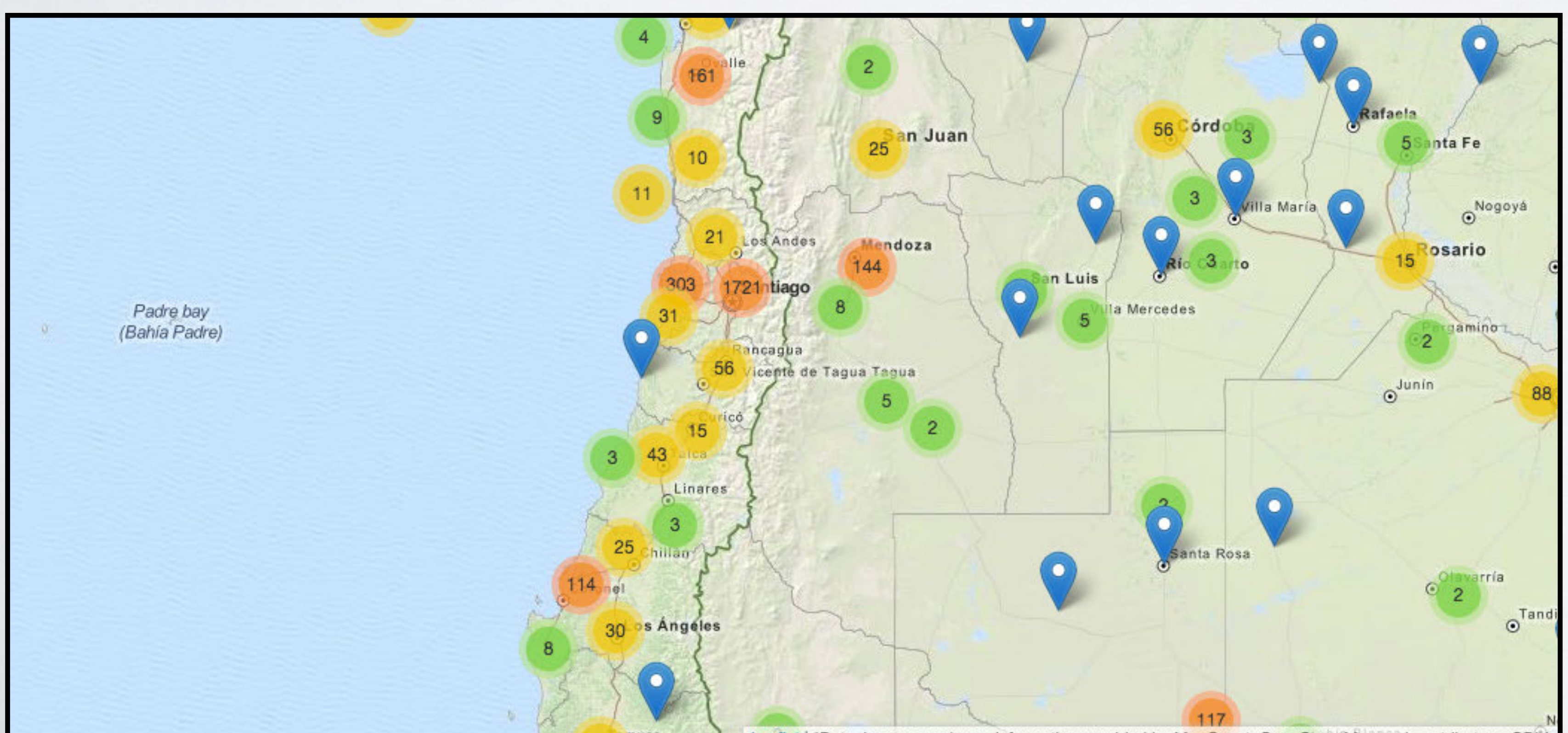
The 2015 Coquimbo earthquake occurred on the plate interface between the Nazca and South America Plates. Rupture occurred near the Peru-Chile trench, the surface expression of the plate boundary.

The mainshock hypocenter is in agreement with the Slab 1.0 modeled plate interface (blue line). The red line (top) shows a schematic of the plate boundary which better captures the flat slab nature of subduction in this region.

USGS
science for a changing world

Earthquake Twitter Detection (@USGSTed)





Twitter detection issued to NEIC in ~45 sec after origin time

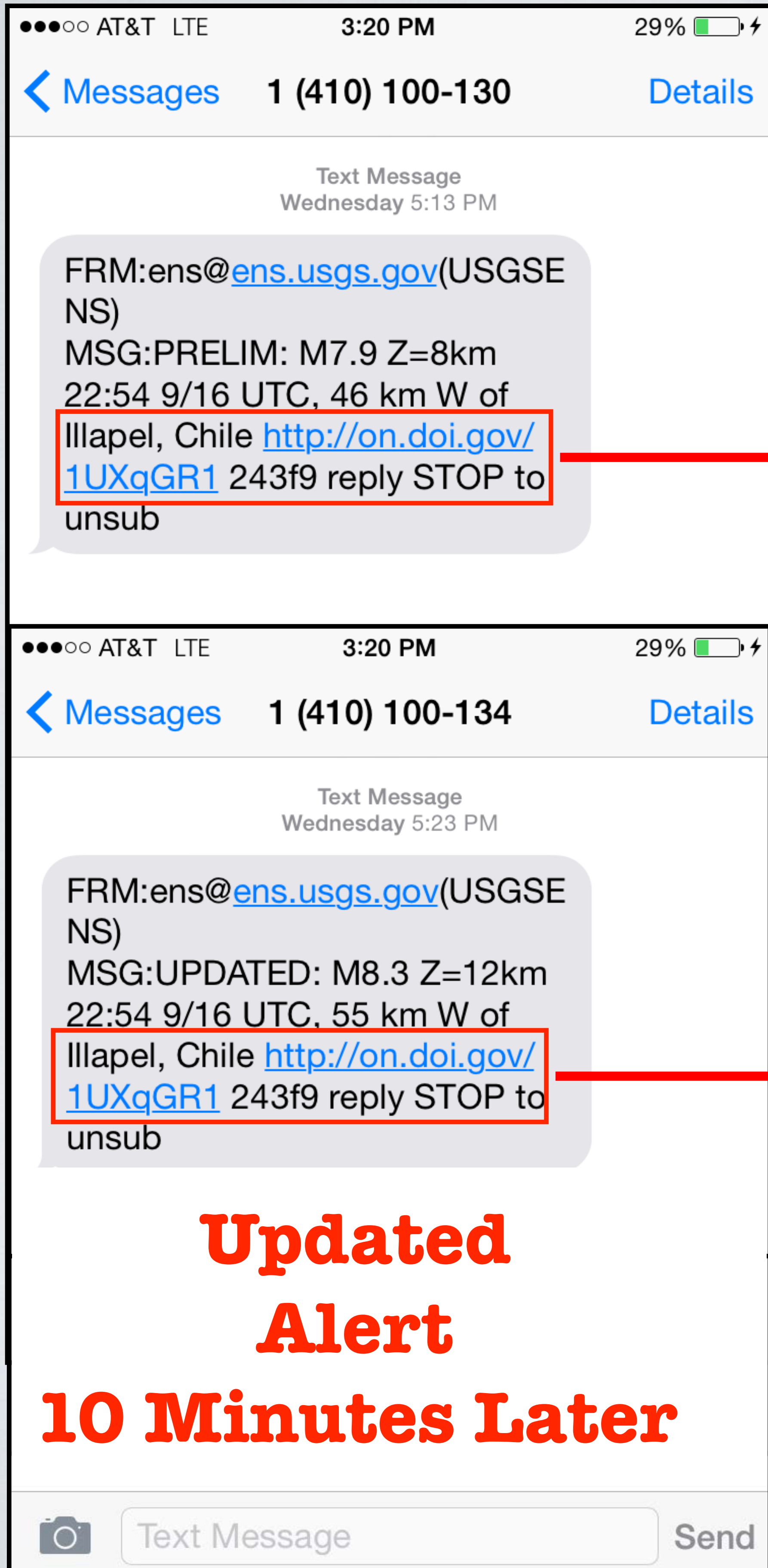
Initial instrumental earthquake location in 99 sec

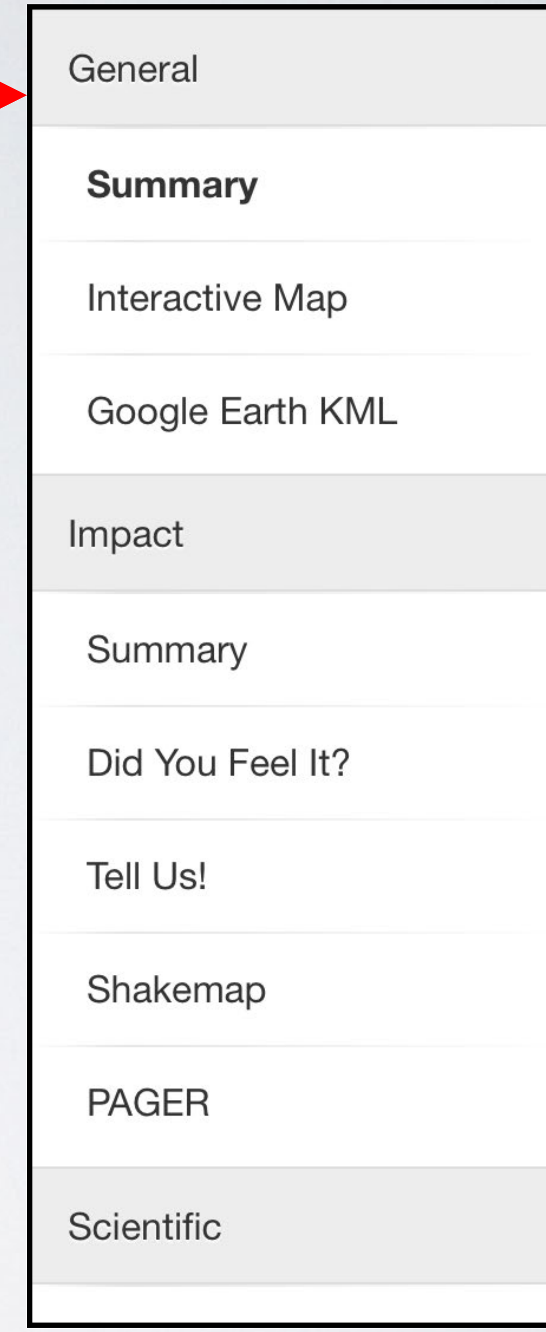
Collected 85,000 "earthquake" tweets (“terremoto” or “temblor”) in the first hour

Large ratio of “terremoto” to “temblor” tweets quickly indicated a large earthquake

USGS
science for a changing world

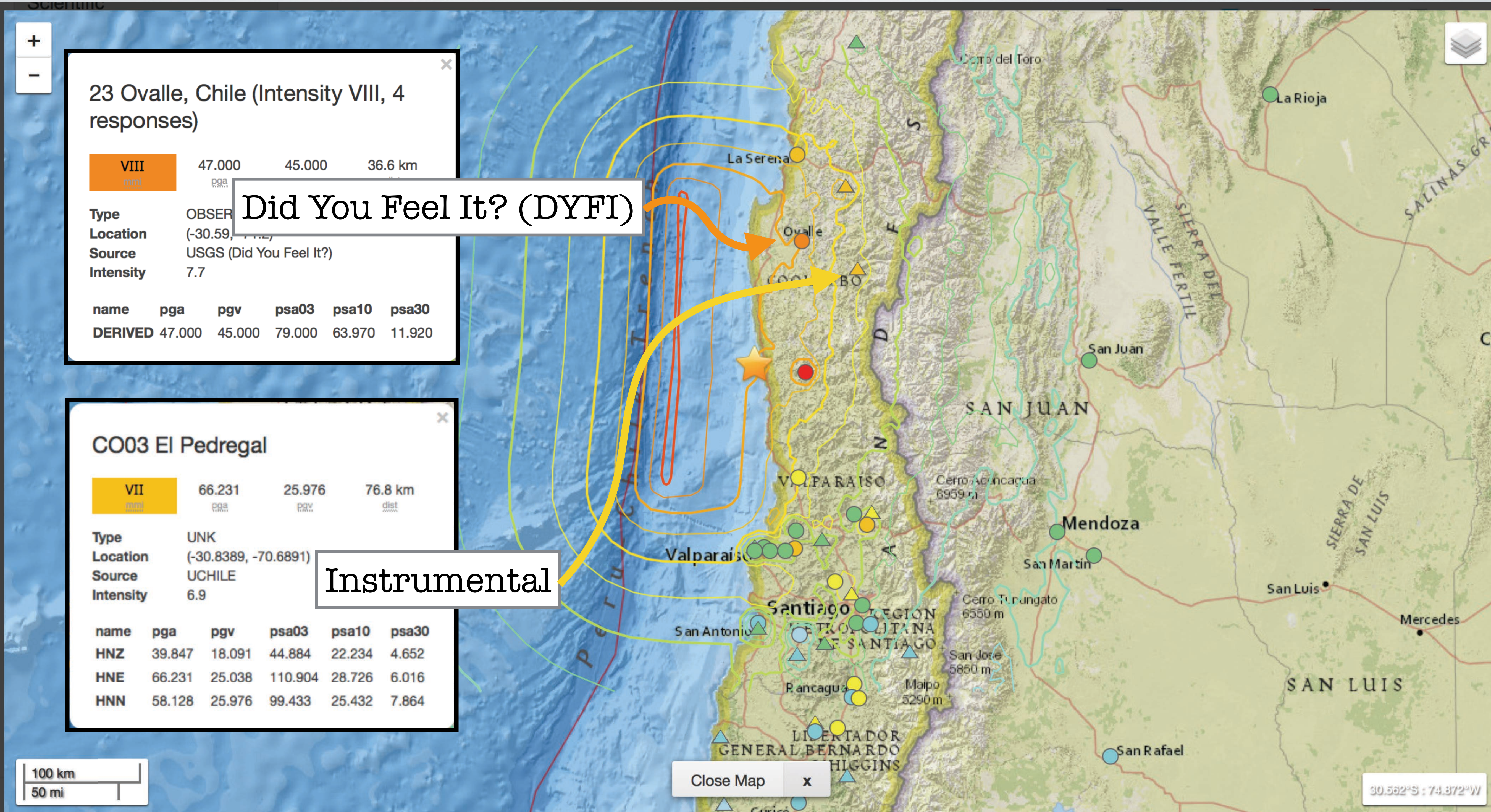
Earthquake Notification





https://twitter.com/USGSted
http://earthquake.usgs.gov/earthquakes/feed/v1.0/
http://earthquake.usgs.gov/earthquakes/map/

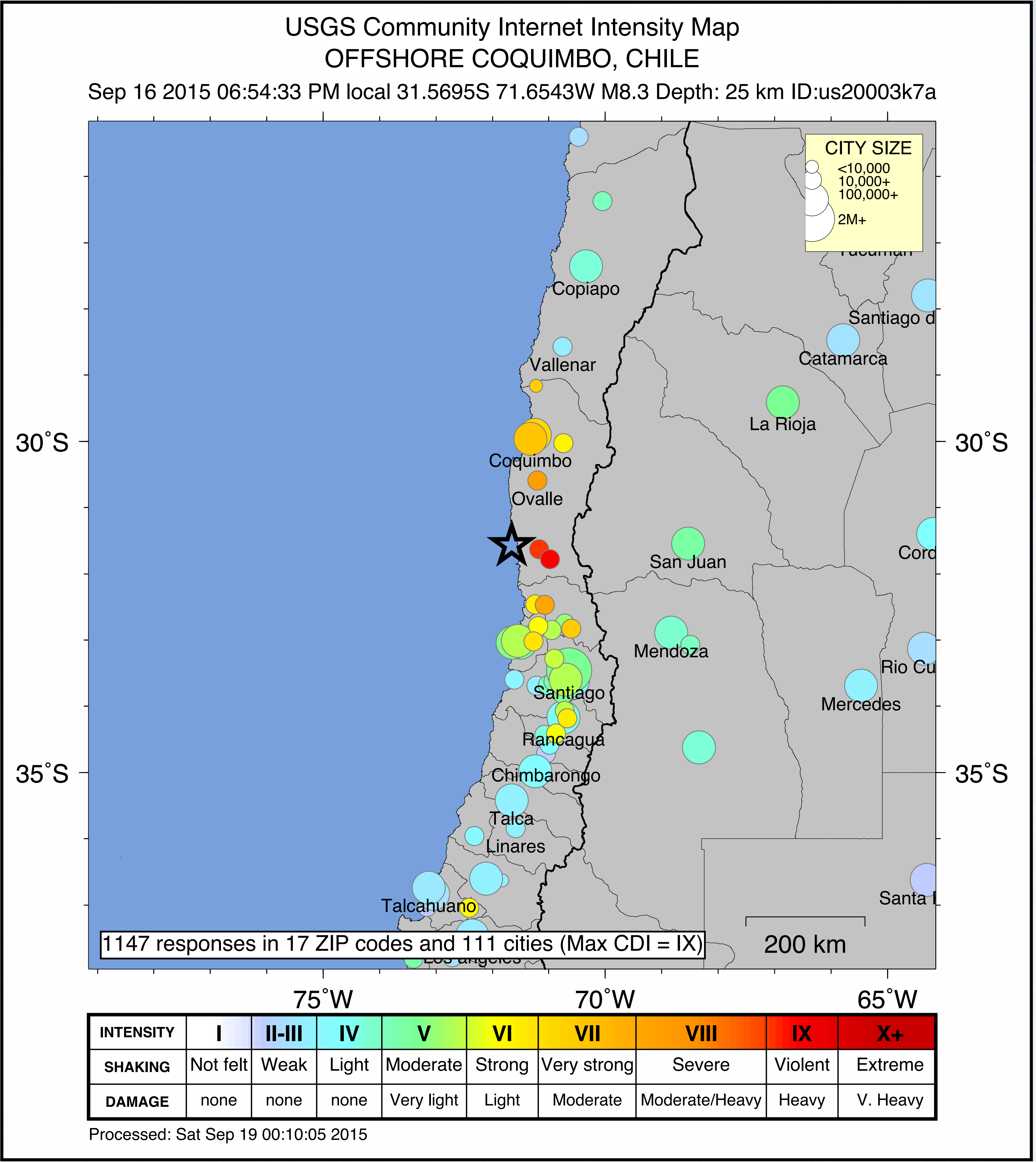
ShakeMap Intensity



INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy

DYFI = circle; Instruments = triangles

USGS
science for a changing world



Did You Feel It? (DYFI)

- > 1000 Responses
- Largest nearby reported intensity of IX
- Moderate shaking (V) reported in Santiago Metropolitan Area

USGS
science for a changing world

Earthquake Shaking — Orange Alert

GSN · ANSS · USAID FROM THE AMERICAN PEOPLE

PAGER Version 8

M 8.3, OFFSHORE COQUIMBO, CHILE

Origin Time: Wed 2015-09-16 22:54:33 UTC (19:54:33 local)
Location: 31.57°S 71.65°W Depth: 25 km
FOR TSUNAMI INFORMATION, SEE: tsunami.gov

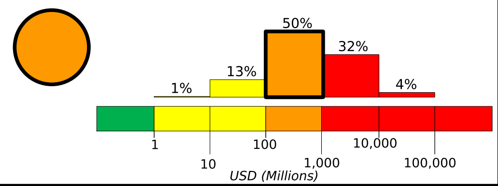
Created: 23 hours, 17 minutes after earthquake

Estimated Fatalities

Orange alert level for economic losses. Significant damage is likely and the disaster is potentially widespread. Estimated economic losses are less than 1% of GDP of Chile. Past events with this alert level have required a regional or national level response.

Yellow alert level for shaking-related fatalities. Some casualties are possible.

Estimated Economic Losses



Estimated Population Exposed to Earthquake Shaking

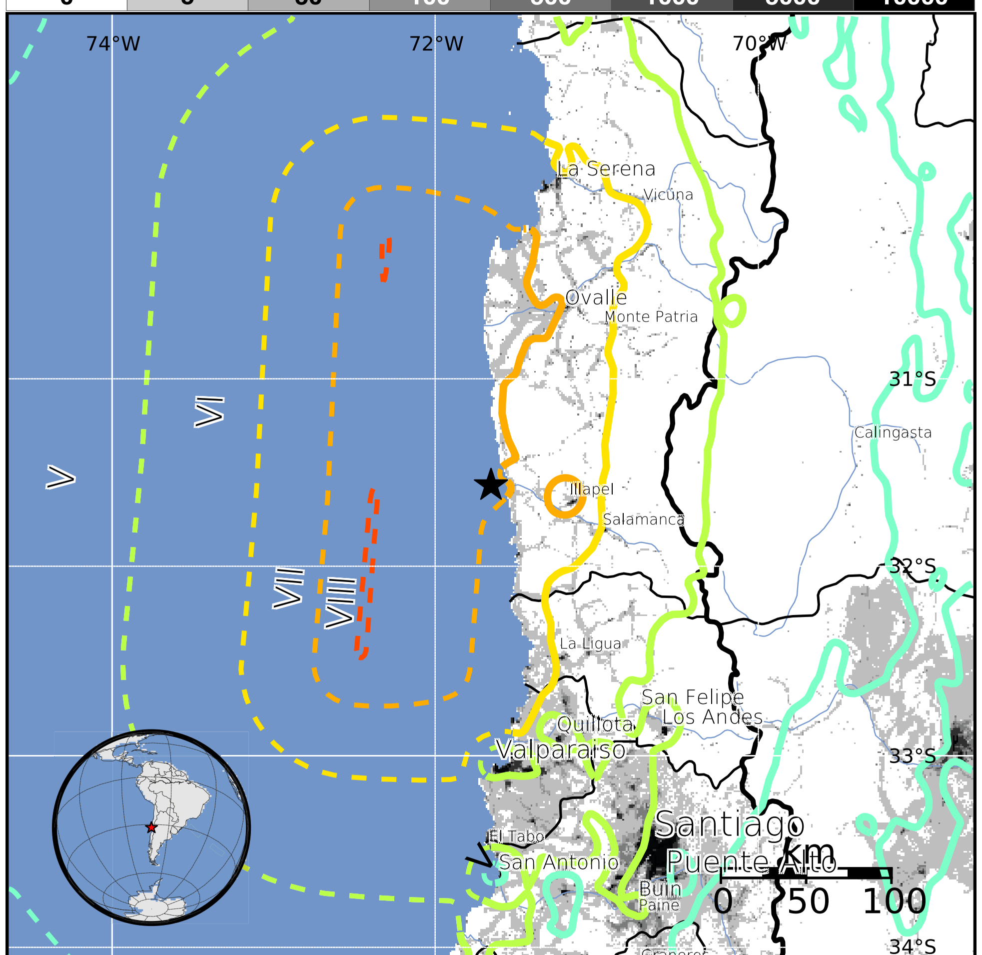
ESTIMATED POPULATION EXPOSURE (k = x1000)		--*	--*	595k*	6,455k*	3,052k*	794k	126k	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0 · 5 · 50 · 100 · 500 · 1000 · 5000 · 10000



Structures:
Overall, the population in this region resides in structures that are resistant to earthquake shaking, though some vulnerable structures exist. The predominant vulnerable building types are low-rise reinforced/confined masonry and adobe block construction.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1973-10-05	168	6.7	VIII(2k)	0
1997-10-15	90	7.1	VIII(3k)	7
1985-03-03	174	7.9	VII(7,023k)	177

Recent earthquakes in this area have caused secondary hazards such as tsunamis, landslides, and liquefaction that might have contributed to losses.

Selected City Exposure

from GeoNames.org

MMI	City	Population
VIII	**Illapel**	23k
VIII	**Ovalle**	77k
VII	**Monte Patria**	14k
VII	**Salamanca**	13k
VII	**La Serena**	155k
VII	**Vicuna**	13k
V	**Santiago**	4,837k
V	Vina del Mar	295k
V	**Valparaiso**	282k
V	**Puente Alto**	510k
V	Mendoza	877k

bold cities appear on map (k = x1000)

PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

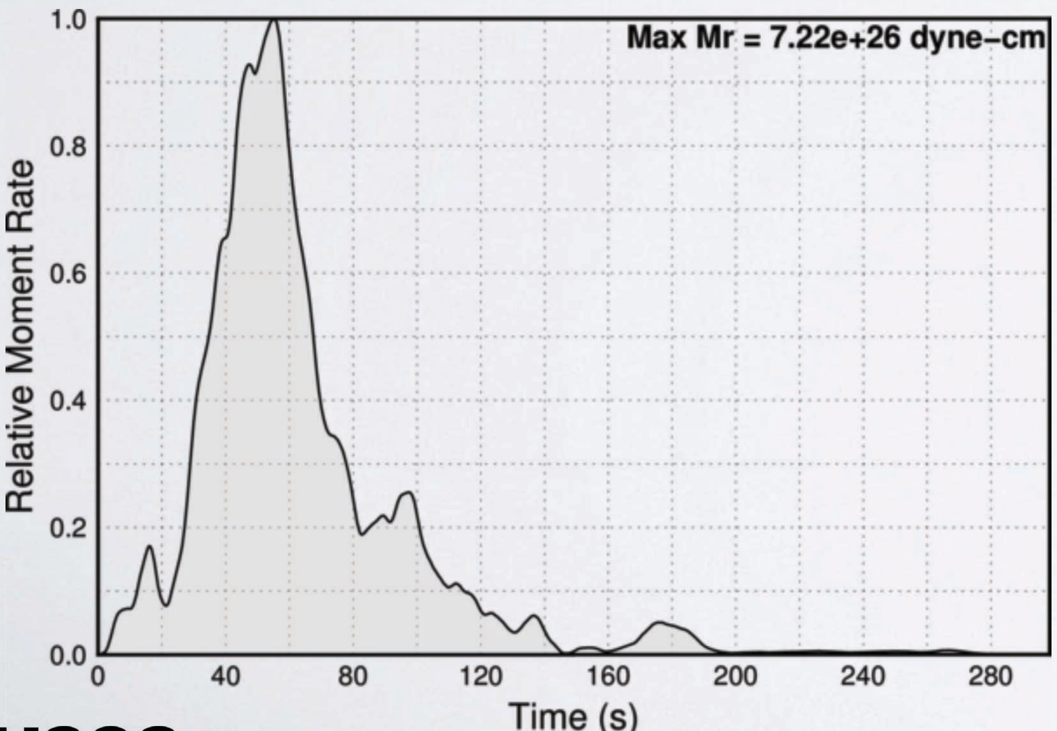
Event ID: us20003k7a

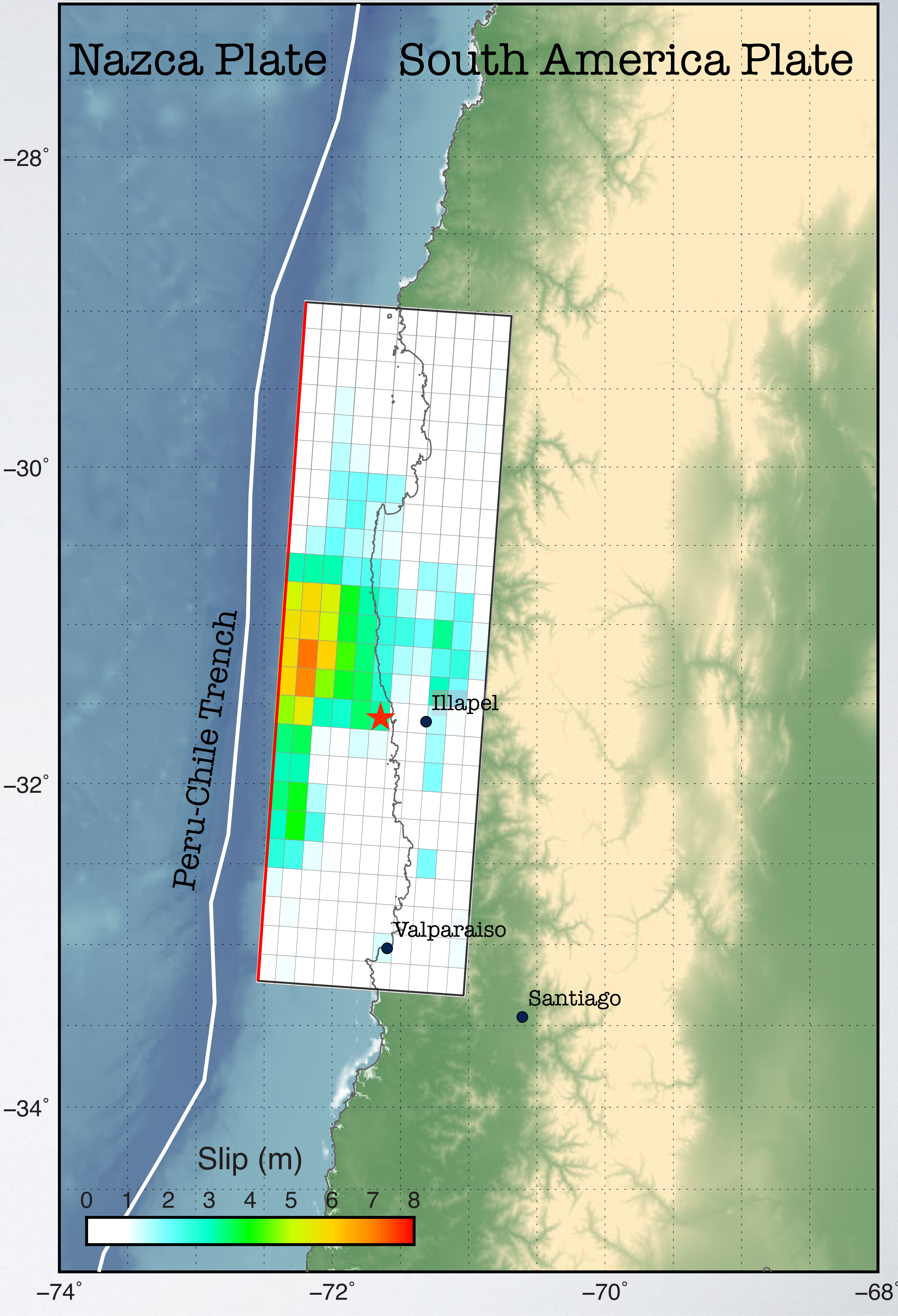
Prompt Assessment of Global Earthquakes for Response (PAGER)

- Median loss estimation:
  - 60 fatalities
  - $650M economic loss
- Chilean Red Cross reported 13 fatalities
- AIR Worldwide estimates insured losses at $600-$900M
- La Oficina Nacional de Emergencia del Ministerio del Interior y Seguridad Pública (ONEMI) reported more than 400 residential buildings were destroyed and 700 residential buildings sustained major damage

Finite Fault Model (FFM)

- M 8.3 mainshock on 9-16-2015
    - 46 km W of Illapel, Chile
    - 229 km NNW of Santiago, Chile
- Rupture initiated on the subduction zone interface at a depth of about 26 km and ruptured mostly up dip toward the Peru-Chile trench
- Slip of >6 m occurred on the shallow portion of the interface near the Peru-Chile trench
- Source duration of ~140 sec

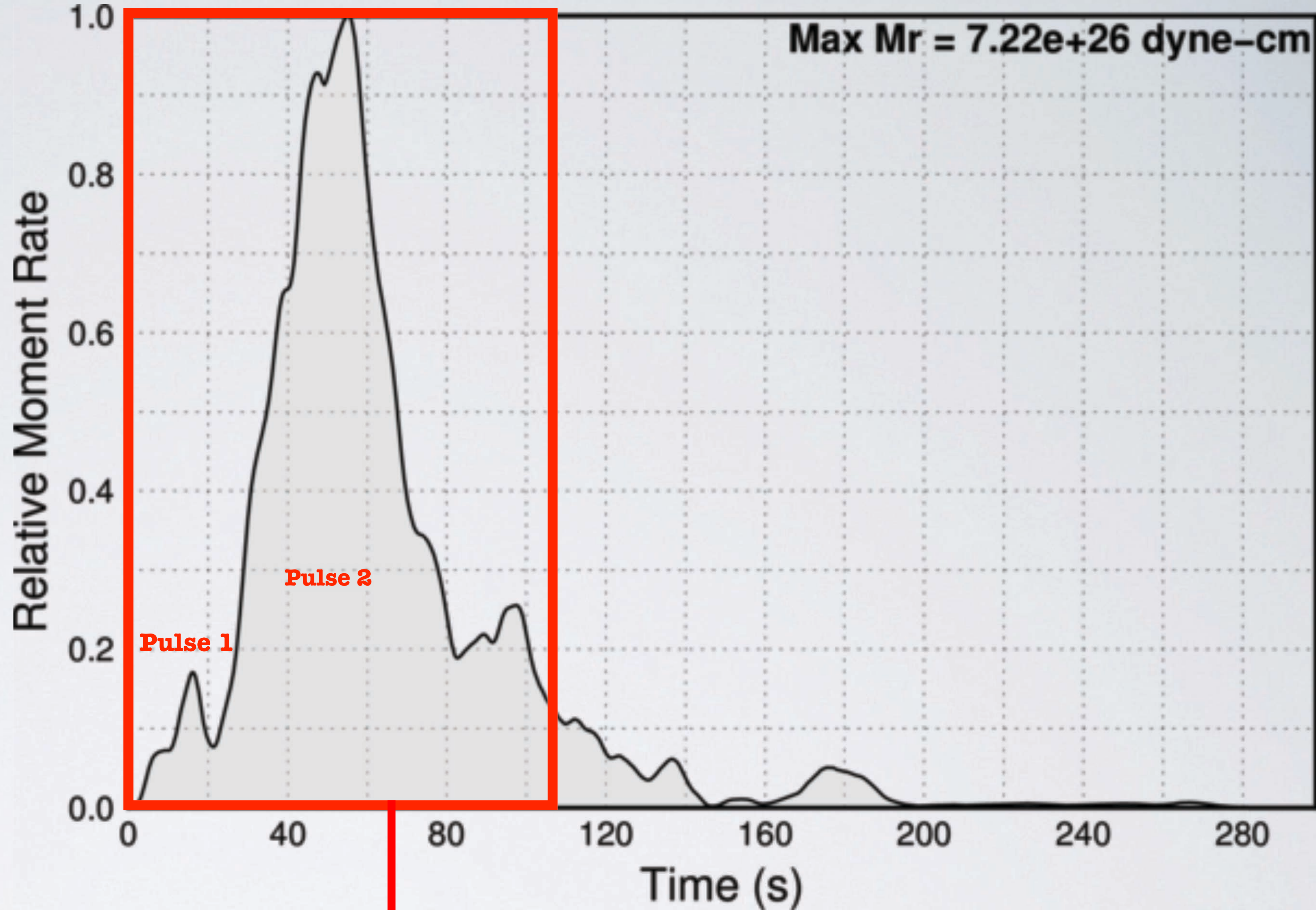


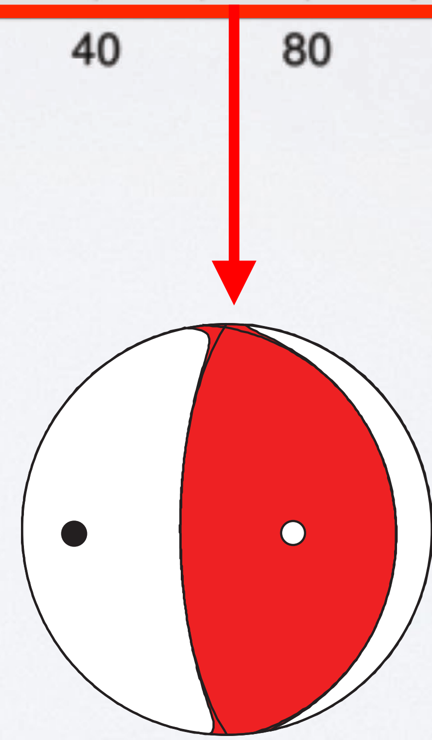


USGS
science for a changing world

Single Source W-Phase Analysis

- Preferred single source W-phase solution consists of a Mw 8.3 thrust faulting event
- The size, location, depth and mechanism of this event are all consistent with its occurrence on the megathrust interface
- Two distinct pulses in the moment rate function indicate unmodeled complexity in the single source solution

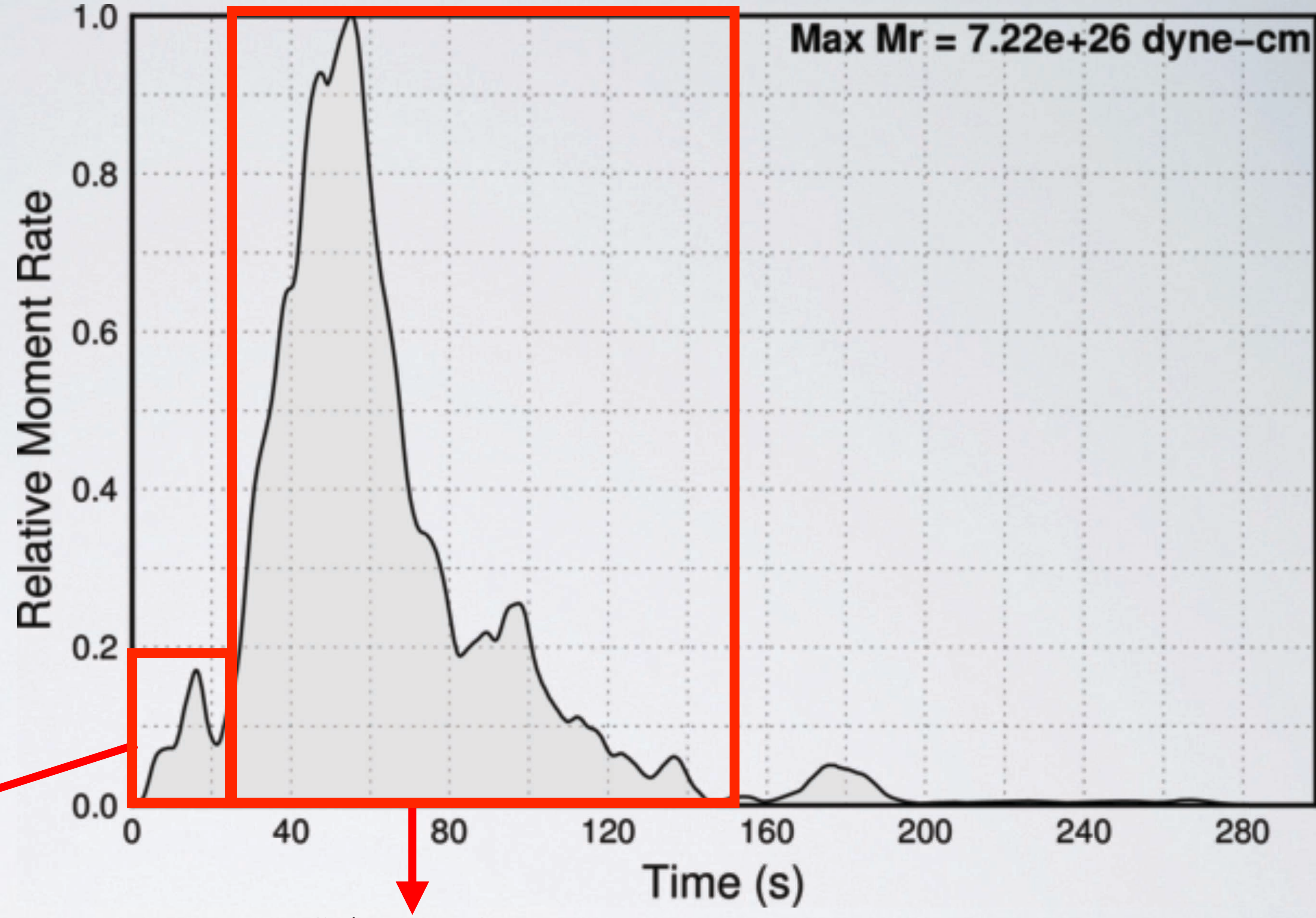




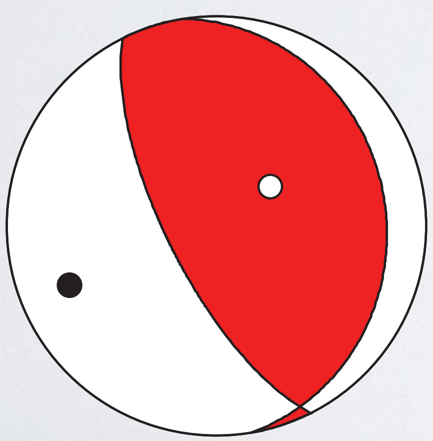
Mw 8.3
Centroid time delay: 53s
Half-duration: 53s
Depth: 25.5 km
$\phi = 353$
$\delta = 19$
$\lambda = 83$

Multiple Source W-Phase Analysis

- Complex rupture involving 2 distinct pulses of moment release
- Initial M 7.2 rupture at a depth of about ~40 km occurred in the 1st 20+ s
- Followed by ~80+ s of M 8+ up-dip megathrust rupture

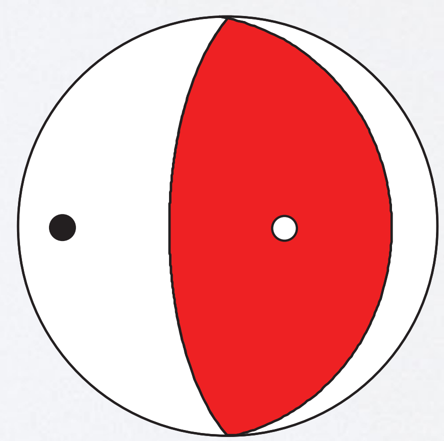


Sub-event 1:



Mw 7.2
Centroid time delay: 20s
Half-duration: 20s
Depth: 40.5 km
$\phi = 350.6$
$\delta = 20.3$
$\lambda = 106.2$

Sub-event 2:

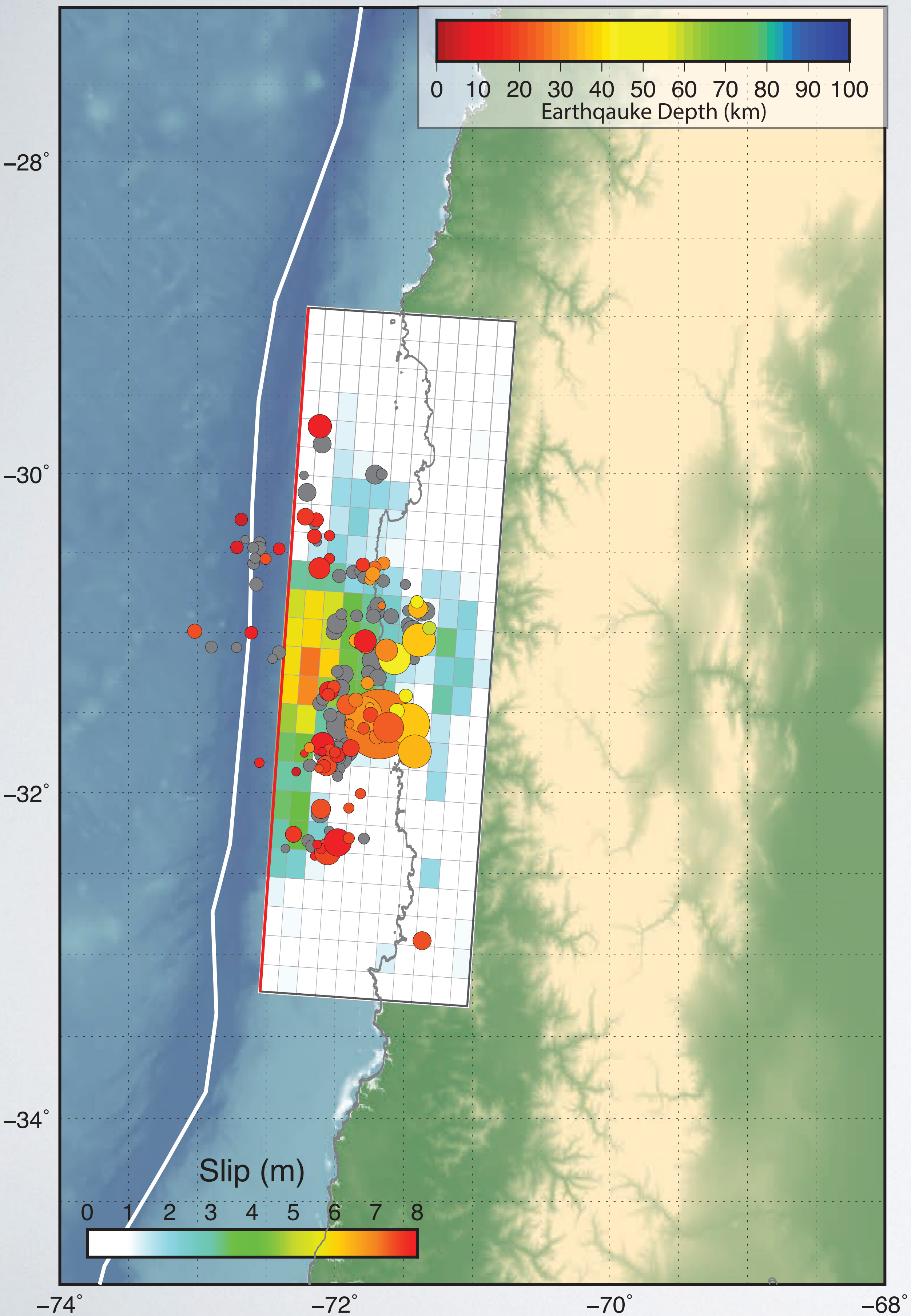


Mw 8.2
Centroid time delay: 52s
Half-duration: 45.7468s
Depth: 23.5 km
$\phi = 357.6^{o}$
$\delta = 22.9^{o}$
$\lambda = 87.5^{o}$

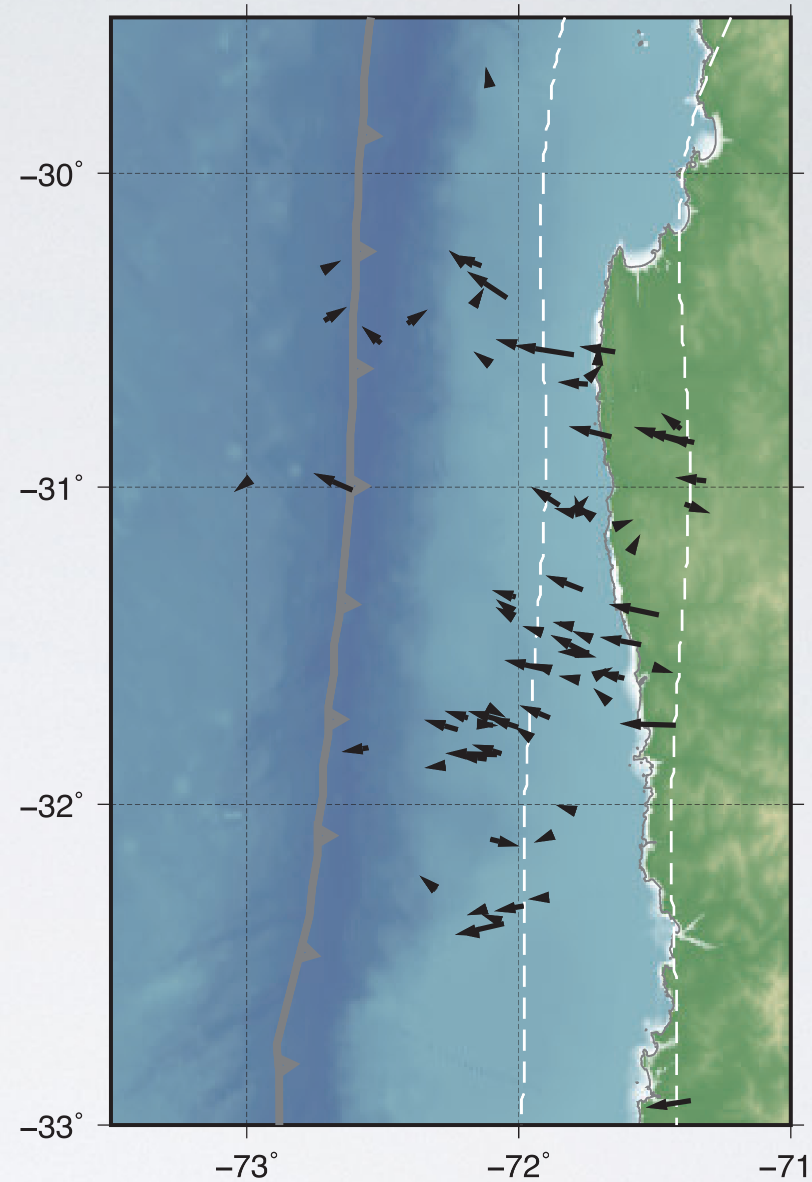
Constraints: The time delay and half-duration of the first sub-event were fixed at 20 sec. (matching the moment rate function) and the dip of the first sub-event was fixed at 20.3º.

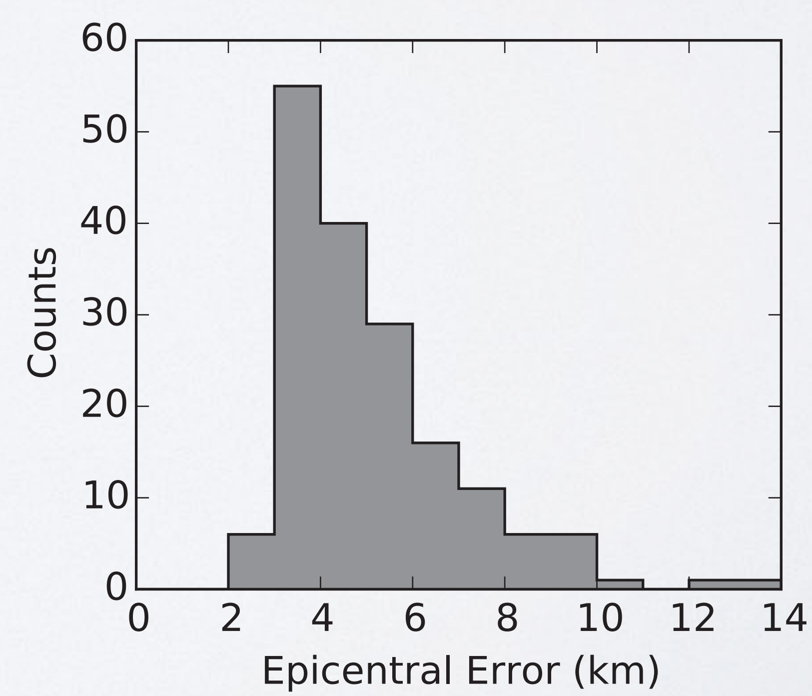
Multiple Event Aftershock Relocations

Relocated Aftershocks compared to FFM



Relocation Vectors



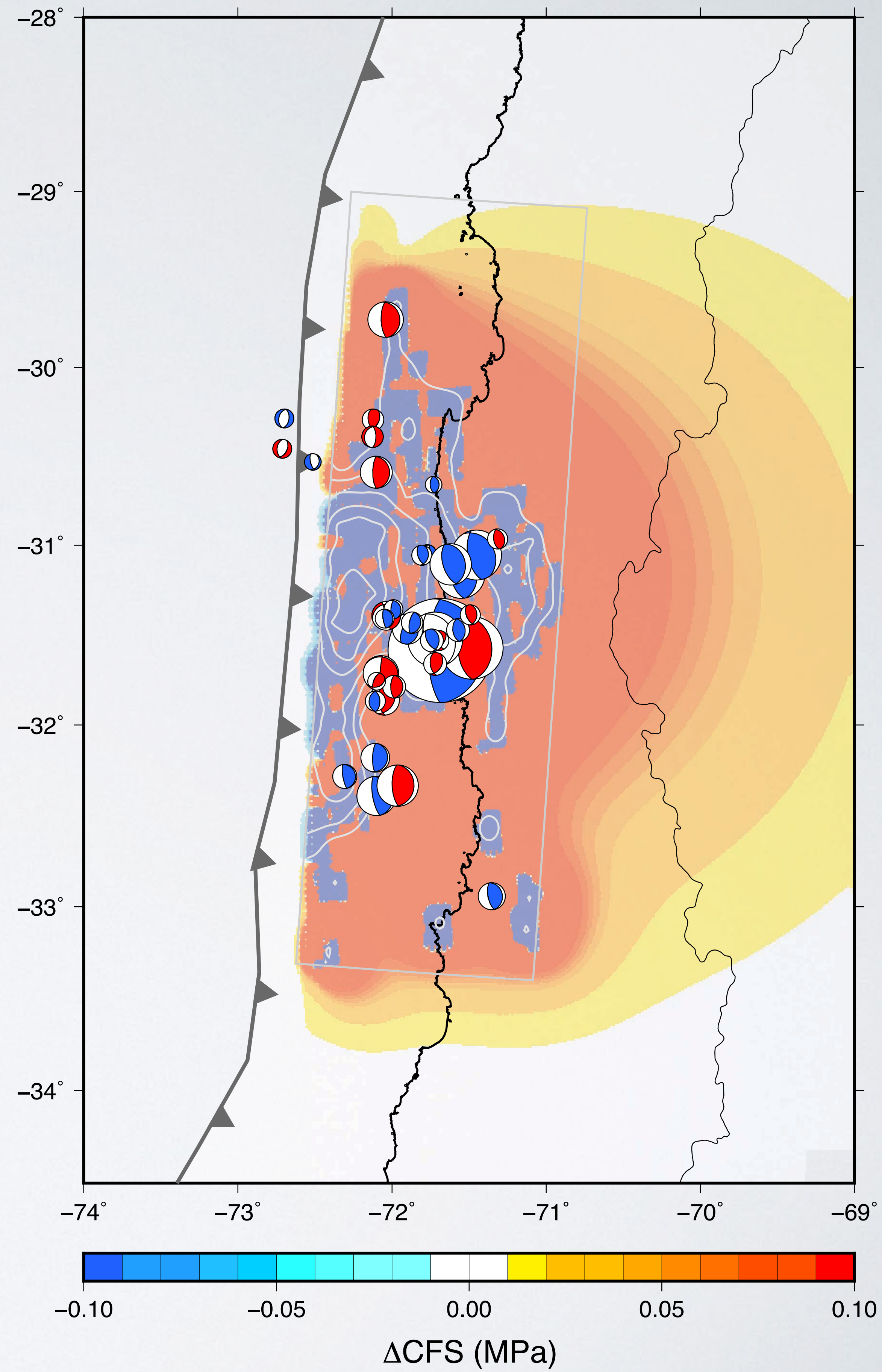


- Depths constrained from waveform modeling (Wphase, RMT, etc.) when possible (colored circles).
- Mainshock and aftershocks relocate ~5-10 km W-NW of the single event locations
- Seismicity largely absent in FFM's region of largest slip

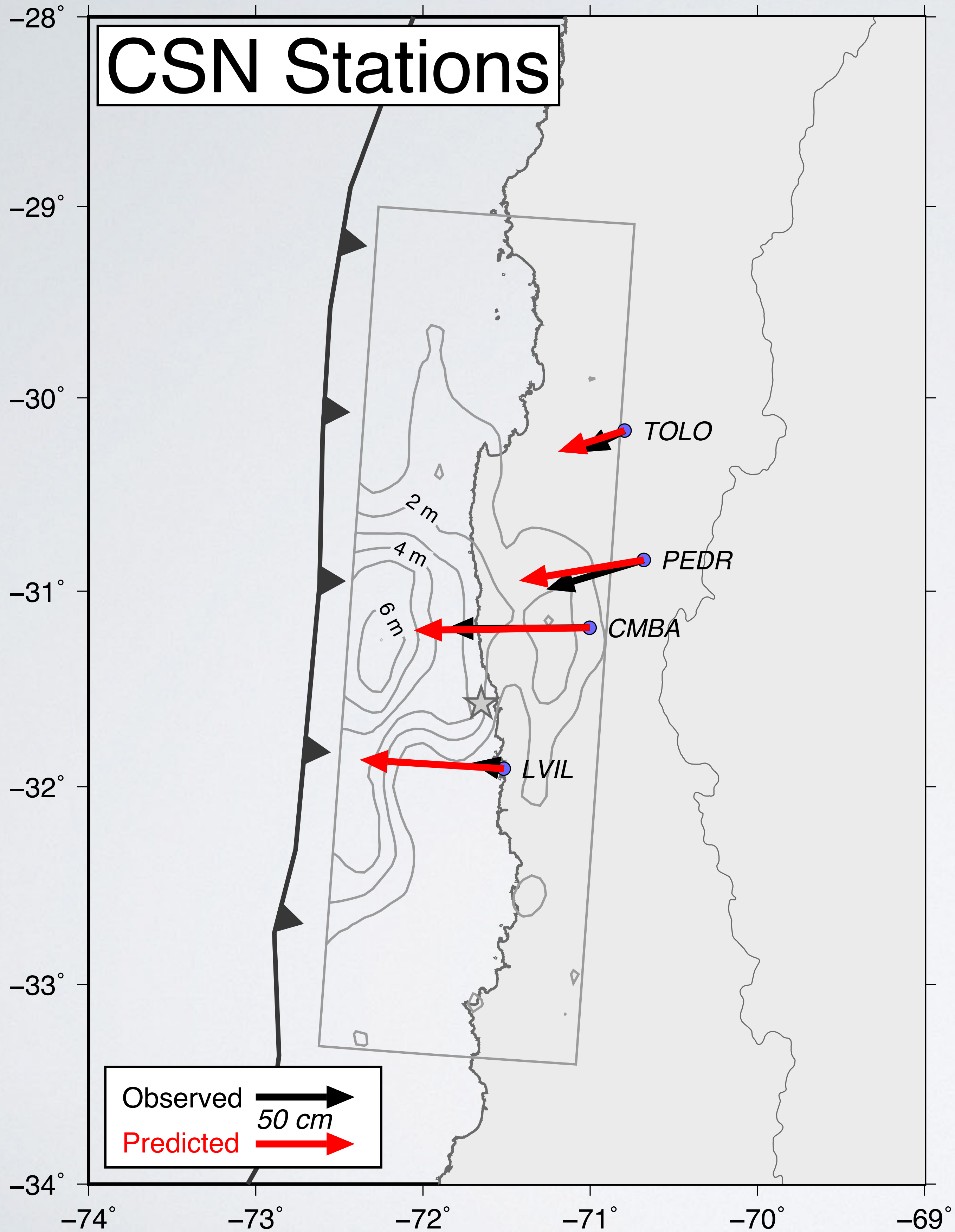
USGS
science for a changing world

Coulomb Stress Change From Mainshock

- Predicted Coulomb stress change from finite fault model
- Coulomb stress change is a measure of how much a fault is brought closer to (red) or farther from (blue) failing
- Background colors show Coulomb stress change resolved on the subduction plate boundary
- Coulomb stress change is also resolved onto earthquake fault planes at their relocated hypocenters; these events are plotted and colored by the Coulomb stress change



USGS
science for a changing world



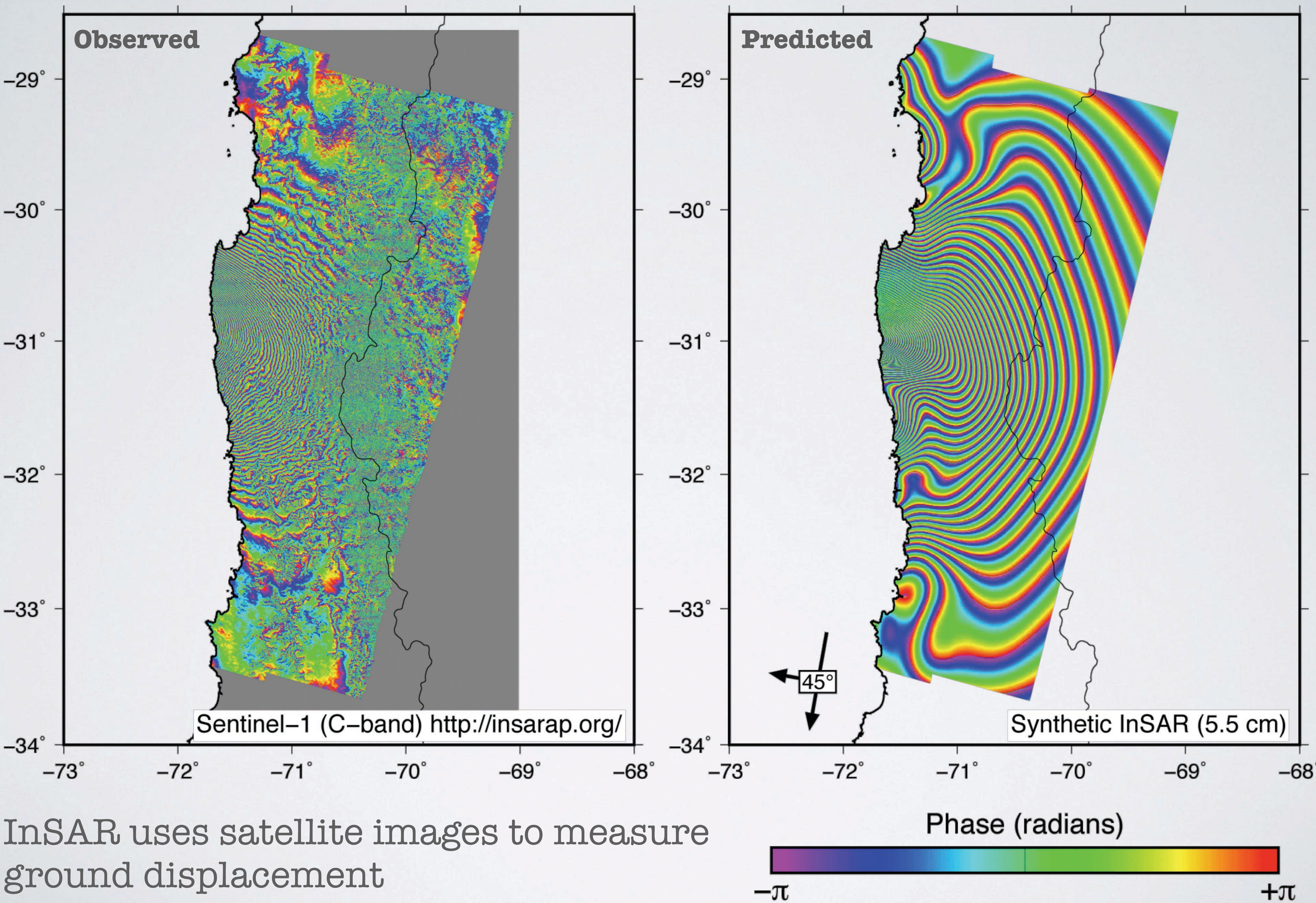
Predicted vs Observed Horizontal GPS Displacements

- Predicted horizontal displacement from teleseismic finite fault model
- Red arrows indicate predicted horizontal displacement from finite fault model
- Black arrows indicate horizontal displacements observed at GPS stations

Data Source:
University of Chile
http://www.csn.uchile.cl/desplazamientos-del-terremoto-de-illapel-2015/

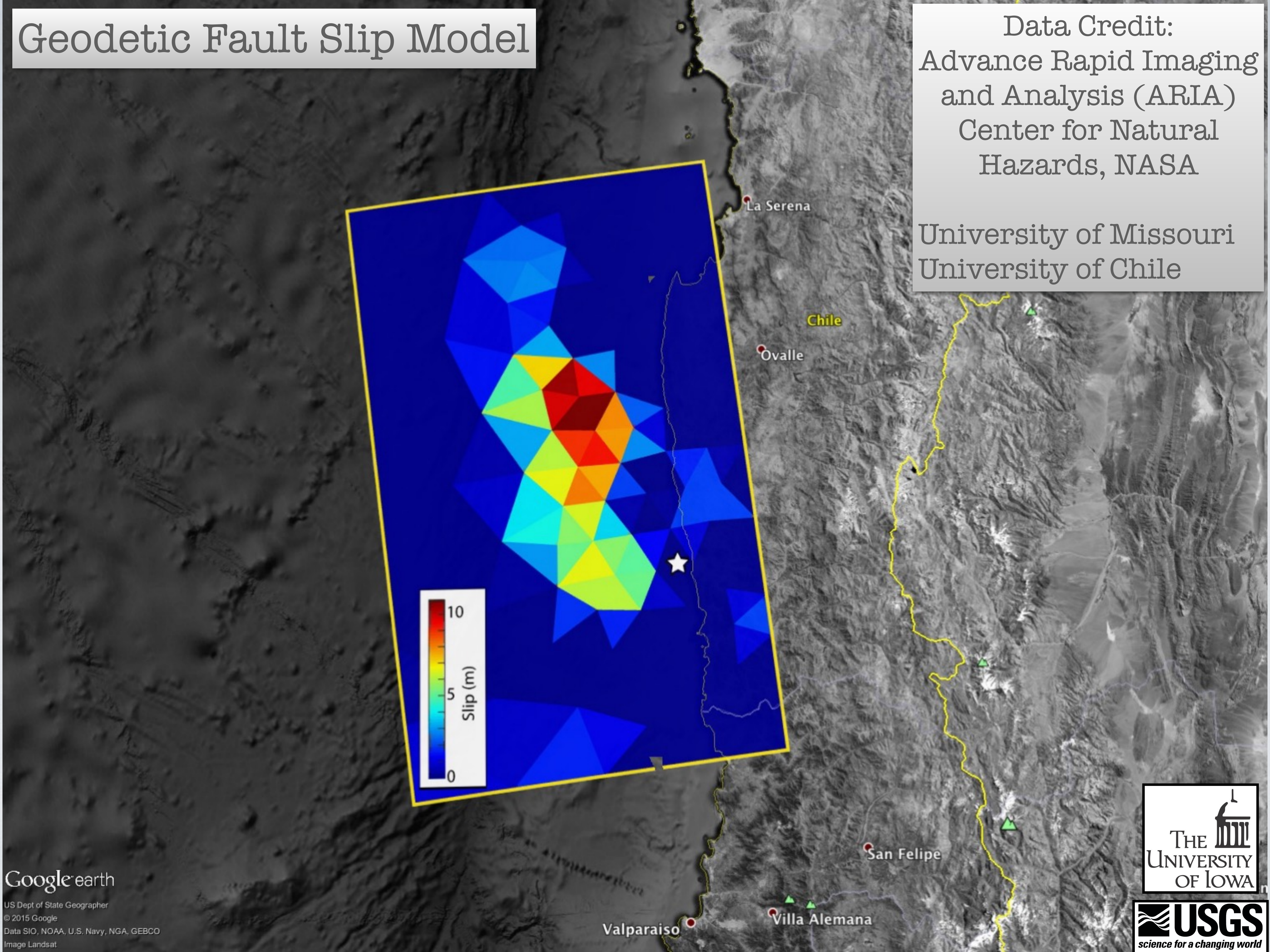
USGS
science for a changing world

Observed InSAR vs Predicted from Teleseismic FFM



InSAR uses satellite images to measure ground displacement

Geodetic Fault Slip Model

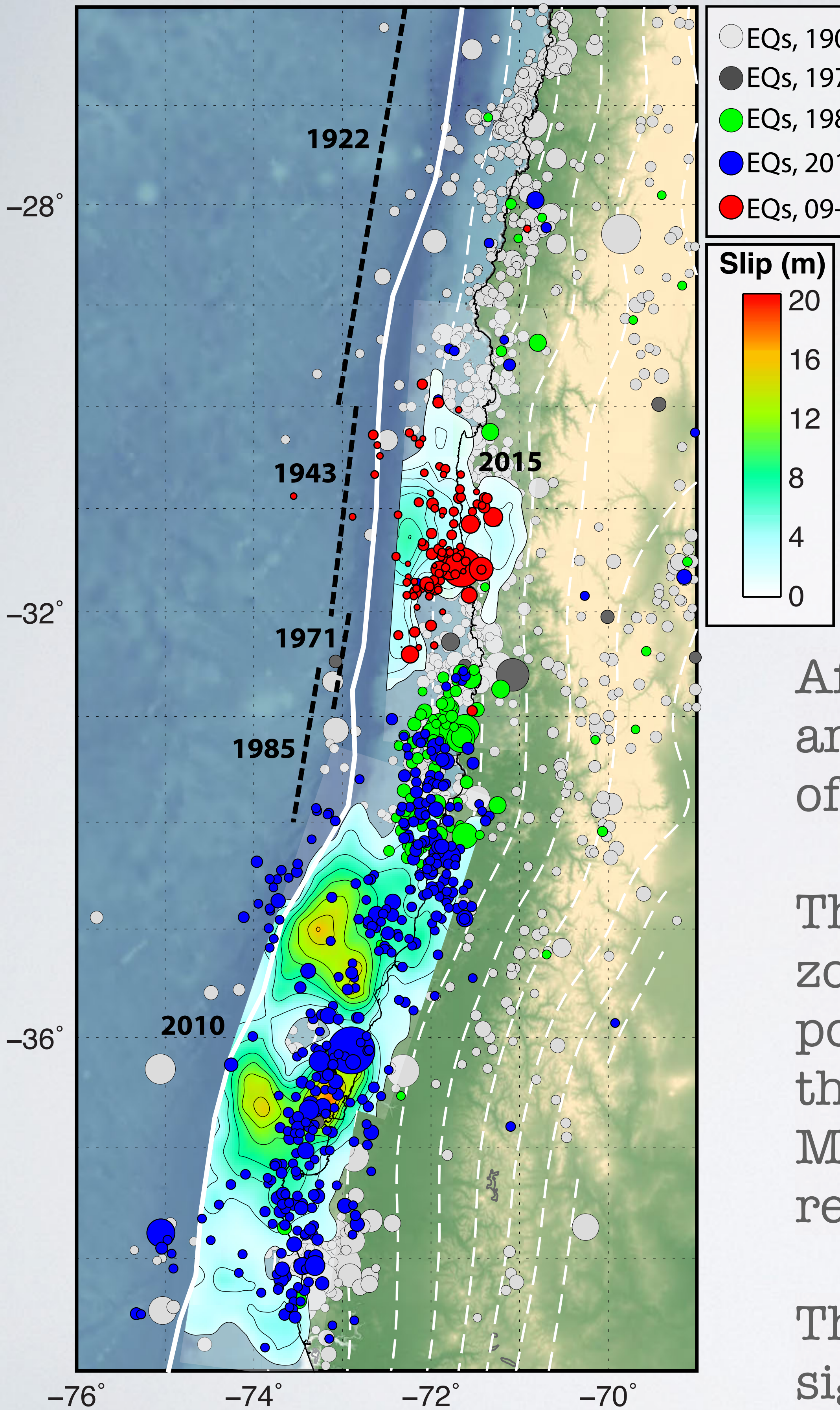


Data Credit:
Advance Rapid Imaging and Analysis (ARIA) Center for Natural Hazards, NASA

University of Missouri
University of Chile

The University of Iowa

USGS
science for a changing world



Summary

Mw 8.3 earthquake is on a shallow angle thrust fault within the subduction zone plate boundary between the Nazca and South America plates

Rupture initiated at a depth of about 26 km with largest rupture (> 6 m) occurring up dip (west), toward the Peru-Chile trench

Aftershocks are primarily in regions adjacent to the area of maximum earthquake slip and down dip (east) of the main fault rupture

The Mw 8.3 earthquake occurred within the rupture zone of the 1943 M8.1 earthquake and into the possible rupture zone of the 1971 M 7.8 earthquake to the south. It is adjacent to the 1922 M8.5 and 1985 M8.0 rupture zones, to the north and south, respectively

The South American subduction zone hosts a significant number of large earthquakes that provide details on strain accumulation and release during the earthquake cycle